# Bottom Pair Production and Search for Heavy Resonances

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**Abstract**

The search for heavy resonances has for long been a part of the physics programme at colliders. Traditionally, the dijet channel has been examined as part of this search. Here, $b\bar{b}$ production is examined as a possible search channel. The chiral color model (flavor universal as well as non-universal) and the flavor universal coloron model are chosen as templates of models that predict the existence of heavy colored gauge bosons. It is seen that, apart from the resonance, the interference of the Standard Model and new physics amplitudes could provide a useful signal. Of particular interest, is the case of the non-universal chiral color model, as this channel may allow the model to be confirmed or ruled out as the reason behind the forward-backward asymmetry in $t\bar{t}$ production.

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# 1 Introduction

The Standard Model (SM) seeks to describe Nature as a realization of the gauge group $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$. While there exists substantial experimental evidence to suggest that this is indeed correct, at least up to the scale of a few hundred GeVs, the picture is far from complete. Several extensions of the SM have been suggested [1] and continue to be suggested in the attempt to redress the 'unsatisfactory' aspects of the model. One common feature among many of these models is the existence of massive particles that couple to a pair of SM fermions and are likely to appear as a resonance in the process $f\bar{f} \to f'\bar{f}'$. Experimental searches for such particles are most often carried out in the dijet channel or in the Drell-Yan process. However, as one wishes to study a fermion-antifermion final state, the $b\bar{b}$ channel is also an option that could be investigated. If the new particles under consideration have only strong interactions, then the Drell-Yan process would not be sensitive to their presence. As for the dijet process, while it may receive contributions from

new strongly interacting particles, sensitivity would be limited by the fact that final states consisting of a quark-antiquark pair not be distinguishable from those with $qq$, $\bar{q}\bar{q}$, $qg$, $\bar{q}g$ or $gg$. On the other hand, $b$-jets can be identified with reasonable accuracy using flavor-tagging techniques. Thus, $b\bar{b}$ production may prove to be useful as a search channel.

In this paper, the reach of the $b\bar{b}$ channel in the search for some classes of new physics(NP) models, namely, the chiral color model (with and without flavor universality) and the flavor universal coloron model, is examined. This channel is of particular importance for the flavor non-universal chiral color model. The observation of forward-backward asymmetry in $t\bar{t}$ production($A^t_{FB}$) caused a slew of models to be proposed as plausible explanations. In a majority of these, new couplings were introduced for the top quark while keeping bottom quark couplings unchanged. The nu-axigluon is an exception to this and a search in the $b\bar{b}$ channel can provide one way to distinguish this model amongst a host of others.

The next section contains a brief description of the models and the existing limits on their constituents. The details of the calculation are discussed in Sections 3 and 4.

# 2 Models

In the Standard Model, the gauge group $SU(2)_L \otimes U(1)_Y$ is broken to $U(1)_{em}$. This has prompted attempts to examine whether QCD may be the remnant of a broken symmetry too. The unifiable chiral color model and the flavor universal coloron model are two models which propose that $SU(3)_C$ is actually a relic of a $SU(3) \otimes SU(3)$ symmetry broken spontaneously at a high scale.

Chiral color models [2] assume the gauge group describing strong, weak and electromagnetic interactions to be $SU(3)_L \otimes SU(3)_R \otimes SU(2)_L \otimes U(1)_Y$. $SU(3)_{R-L}$ is sought to be broken spontaneously at a scale comparable to the scale of electroweak symmetry breaking. $SU(3)_{R+L}$ remains and is identified with $SU(3)_C$. Thus, in these models, there exists an octet of massive colored gauge bosons (axigluons) alongside an octet of massless ones (gluons). The axigluons($A$) have an axial vector coupling to quarks which has the *same* strength ($g_s$) as the gluon-quark coupling. These models also require the existence of additional fermions and colored scalars. Infact, in the most optimistic scenario [3], five generations of quarks and leptons, three Higgs doublets and additional electrically neutral as well as charged fermion multiplets in 'non-standard' representations are predicted. This gives rise to a model that, besides replicating many of the successes of the Standard Model, is rich in high scale physics and is unifiable at a scale much lower than that for the latter.

Initially the scale of chiral-color breaking was assumed to be the same as that of electroweak symmetry breaking and axigluons were expected to have mass $\sim 250$ GeV. Early experimental bounds obtained from measurements of $\Upsilon$ decays and hadronic cross-sections in $e^+e^-$ collisions [4] ruled out $M_A < 50$ GeV. The region 50 GeV $< M_A <$ 120 GeV was ruled out by considering effects on hadronic decays of $Z^0$ and the possibility of associated production of axigluons [5]. Dijet production in hadronic colliders has been repeatedly surveyed for signals of a resonant axigluon [6]. A series of searches at the Tevatron in this channel [7] have now

resulted in exclusion of $M_A < 1250$ GeV at 95% confidence [8]. The use of forward-backward asymmetry [1] as a signal for axigluons has also been studied [9] and possible limits from top production data have been considered in Refs. [10–12].

More recently, flavor non-universal versions of the original chiral color model have been proposed [13, 14] as possible explanations of the forward-backward asymmetry observed in $t\bar{t}$ production at the Tevatron [15, 16]. In particular, the model in Ref. [13] contains four quark generations and is based on the gauge group $SU(3)_A \otimes SU(3)_B \otimes SU(2)_L \otimes U(1)_Y$. The gluon and the flavor non-universal axigluon($A'$) are admixtures of the gauge bosons corresponding to $SU(3)_A$ and $SU(3)_B$ with $\theta_{A'}$ being the mixing angle. The coupling of the non-universal axigluon [2] consists of a vector and an axial-vector part. While the vector coupling is generation universal ($-g_s \cot 2\theta_{A'}$), the axial-vector coupling is not, with $g_A^q = -g_s \,\mathrm{cosec}2\theta_{A'}$ for the first two generations and $g_A^t = +g_s \,\mathrm{cosec}2\theta_{A'}$ for the other two. Demanding that the couplings be perturbative, restricts $10^\circ < \theta_{A'} < 45^\circ$.

Although, the Lorentz structure of the couplings is the similar to that in the original chiral color model, the non-universal nature of the couplings implies that the mass limits on the former from the dijet search, are not directly applicable. However, as the main motivation behind the proposition was to explain the observed $A_{FB}^t$, the parameter space can be constrained using measurements in the top sector, such as the $t\bar{t}$ cross-section, $A_{FB}^t$ and the $m_{t\bar{t}}$ spectrum [13]. In particular, the apparent agreement of the invariant mass distribution (which is reported for $m_{t\bar{t}}$ upto 1400 GeV) with the SM, can be used immediately, albeit somewhat naively, to put a lower limit of 1400 GeV on $M_{A'}$.

In the flavor universal coloron model [17], the high scale color gauge group is $SU(3)_I \otimes SU(3)_{II}$. This is broken to $SU(3)_C$ at the TeV scale. Here again, there is an octet of massive colored gauge bosons (colorons) in addition to gluons. The original model [18] was aimed at constructing a dynamical mechanism for electroweak symmetry breaking involving a $\langle \bar{t}t \rangle$ condensate. In this model, the third generation quarks belonged to a different representation of $SU(3)_I \otimes SU(3)_{II}$ as compared to the other quark families. However, in the flavor universal version of the model, all quarks transform as $(1, 3)$ under the extended color gauge group. The couplings are proportional to $\xi_1$ and $\xi_2$ for $SU(3)_I$ and $SU(3)_{II}$ respectively with $\xi_1 \ll \xi_2$. The coupling of the coloron($C$) to quarks is then proportional to $\gamma_\mu \cot \xi$, where, $\xi$ is the mixing angle and $\cot \xi = \xi_2/\xi_1$. An additional scalar multiplet, transforming as $(3, \bar{3})$, effects the symmetry breaking. Initially, this model was proposed in order to explain excess seen in the inclusive jet cross-section in the high $E_T$ region by the CDF experiment at the Tevatron [19]. With increase in statistics and improvement in both theoretical calculations and exprimental techniques, the agreement between theory and experiment has improved considerably [20]. However, the model itself continues to be of interest as it can accomodate, within its framework, a theory with composite quarks [17]. Further, as in the case of the original topcolor proposal [18, 21], the flavor universal version too can provide a scheme for dynamical EWSB via formation of a $\langle \bar{t}t \rangle$ condensate [22].

[1] Axial-vector coupling of axigluons to quarks implies that interference between gluon-mediated and axigluon-mediated processes can give rise to a forward-backward asymmetry. This is discussed in detail later.

[2] This will henceforth be referred to as the nu-axigluon for purposes of disambiguation.

The original proponents of the model [17], placed the limit $M_C/\cot\xi > 450$ GeV required to keep corrections to the electroweak $\rho$ parameter within allowed limits [23]. In addition, demanding that the model remain in its Higgs phase at low energies, results in an upper limit $\sim 4$ on the value of $\cot\xi$ [24]. The phenomenology of colorons was studied in detail in Ref. [24,25] wherein dijet data from the Tevatron [26–28] was used to place a lower limit of 870 GeV and 1 TeV on $M_C$ for $\cot\xi$ values of 1 and 2 respectively, and the lower limit on $M_C/\cot\xi$ was raised to 837 GeV. Sensitivity to this variety of new physics is also expected in the top sector and this has been explored in Refs. [11,29]. The latest measurement of dijet mass spectrum at the CDF experiment at the Tevatron, however, rules out the existence of flavor-universal colorons with mass below 1250 GeV [8].

### 2.1 Search Efforts

As mentioned earlier, in the search for axigluons and colorons, the dijet channel has been studied extensively and has been the focus of most experimental searches. Rates have been calculated for on-shell production of axigluons/colorons followed by decay and this has been used for comparison with data. Some searches have also been carried out in the $t\bar{t}$ channel [12]. It is clear that a (nu-)axigluon/coloron resonance, if present, will also affect $b\bar{b}$ production rates. While both the CDF and D0 experiments have vast B-physics programmes, they are mostly concerned with studying properties of B-mesons [30]. The potential of the $b\bar{b}$ channel in searches for heavy resonances remains largely untapped.

In the case of the models described above, $qg$ and $gg$ dijet final states are not sensitive to the new particles and create a background. On the other hand, t-channel processes such as $qq' \to qq'$, while getting contributions from new physics, tend to render difficult, the task of identification of a resonance structure in the dijet invariant mass spectrum. This is specially true when $M_{boson} \sim 1$ TeV and the resonance is a broad one to begin with [3]. On the other hand contribution to $b\bar{b}$ production from the $t$-channel is negligible. This, coupled with advancements in $b$-tagging algorithms may be exploited in strengthening the search for (nu-)axigluons and colorons as well as other new particles with similar interactions.

## 3 $b\bar{b}$ production

At a hadron collider, $b\bar{b}$ production gets contributions from the processes $q\bar{q} \to b\bar{b}$ and $gg \to b\bar{b}$. At the centre-of-mass energies associated with currently operational colliders, namely, the Tevatron and the LHC, production is dominated by the gluon initated process. However, in the high invariant mass region (in which we are interested), it is the quark initiated process which dominates.

The presence of (nu-)axigluons or colorons modifies the amplitude for the quark initiated process. The $b$ density in protons and anti-protons is negligible and hence the major contri-

[3]Efficiency factors associated with the reconstruction of jets also lead to broadening of the resonance peak. However, for (nu-)axigluons and colorons in the mass range $\sim 1$ TeV, the natural width itself is large.

bution accrues from the s-channel process $q\bar{q} \to b\bar{b}$, mediated by a (nu-)axigluon or a coloron in addition to a gluon[4]. This makes for a distinct, albeit broad, peak[5] in the $b\bar{b}$ invariant mass ($m_{b\bar{b}}$) spectrum. The analytic expressions for the differential cross-section are analogous to those for $t\bar{t}$ production [11, 13] with $m_t \to m_b \approx 0$. The width for the new gauge bosons is about 10% of the mass. Thus, for $M_{new} \sim$ a few hundred GeVs, the large width implies that the narrow-width approximation is no longer valid and the off-shell contribution must also be taken into account. For axigluons and nu-axigluons, there are terms proportional to odd powers of $\cos\theta$ which give rise to a forward-backward asymmetry in the angular distribution. In contrast, $\cos\theta$ dependence for the coloron case is identical to that in the pure SM and is forward-backward symmetric. The interference between the coloron and gluon mediated amplitudes is negative in the region $\hat{s} < M_C^2$ and causes the $m_{b\bar{b}}$ spectrum to dip before peaking.

The gluon initiated process remains unaffected by the presence of (nu-)axigluons/colorons and forms the chief SM background. The corresponding analytic expression is available in Ref. [31]. Here, the $t$-channel and $u$-channel contributions get enhanced in the region where $\cos\theta \to 1$, i.e. in the low $p_T$ region. Moreover, the low threshold for $b\bar{b}$ production implies that it is easily attained with low values of Bjorken $x$, for which, gluon densities are larger than quark densities. Hence, the dominant contribution, particularly in the low $p_T$ and low $\sqrt{\hat{s}}$ region, arises from this process.

# 4 Numerical Results

In this study, the contribution of (nu-)axigluons and colorons to $b\bar{b}$ production is calculated at the parton level. CTEQ6L parton distribution functions [32] are used. The factorization scale is chosen to be $E_T$. The renormalization scale for $\alpha_s$ is $E_T$ everywhere except in the calculation of decay-widths, where, it is set to be the mass of the relevant boson. Other chosen parameters include $\alpha_s(M_Z) = 0.118$ (consistent with CTEQ6L), $m_t = 172$ GeV [33] and all other $m_q = 0$. Production rates are computed for the Tevatron ($\sqrt{s}$=1.96 TeV) as well as the LHC ($\sqrt{s}$=7 TeV).

As mentioned earlier, there is a an enhanced contribution to the SM $gg \to b\bar{b}$ process from the low $p_T$ and $\sqrt{\hat{s}}$ regions. To reduce this background, appropriate cuts need to be imposed on $p_T$. Further, the identification of a $b\bar{b}$ final state requires a double b-tag. b-tagging efficiency is low for high rapidity($y$) regions [34] and this restricts the $y$-range that can be taken into account. The details of the choice of cuts, efficiency factors etc. for the two colliders are given in Table 1.

Contributions to the cross-section also appear from the next-to-leading order(NLO). The new particles being heavy, the additional contribution to the total cross-section from the NLO is expected to be dominated by the SM corrections and hence, in the absence of full NLO calculations incorporating contributions from the new physics models under consideration, only the SM K-Factor for $b\bar{b}$ production at the Tevatron is calculated. MC@NLO [35] is used

[4]Electroweak contributions can be neglected as they are suppressed by a factor $\alpha_{EW}^2/\alpha_s^2$ and hence small.
[5]provided the mass is within the c.m. energy range of the collider

| | $\epsilon_b$ | $\epsilon_{mistag}$ | $p_T^{min}$ | $\lvert y\rvert^{max}$ |
|---|---|---|---|---|
| TeV | 0.3 | 0.030 | 100 GeV | 1.0 |
| LHC | 0.4 | 0.012 | 500 GeV | 1.3 |

Table 1: *$p_T^{min}$ is the value of $p_T$ at which $q\bar{q} \to b\bar{b}$ starts dominating over $gg \to b\bar{b}$. The values mentioned above correspond to the minimal choice and lead to maximum signal significance. The $|y|$ cuts are designed to exclude the regions where b-tagging efficiency is very low [34, 36].*

for this purpose. The dependence of the K-Factor on the $p_T$ cut is also studied. For the range of $p_T^{min}$ examined, it is seen 1 that, the dependence is mild and the K-Factor varies between 1.17 and 1.47.

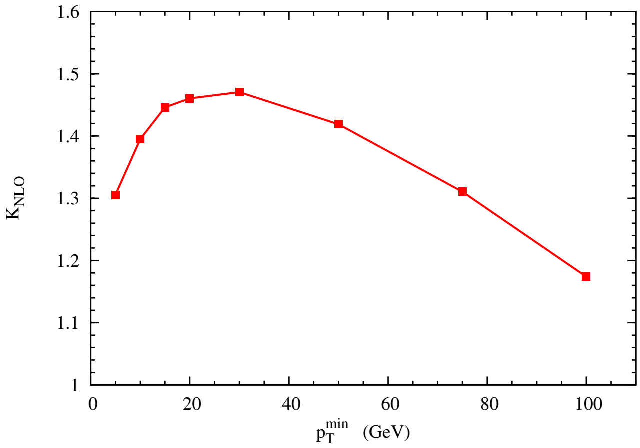



Figure 1: *Dependence of the NLO K-Factor on the $p_T$ cut.*

## 4.1 At the Tevatron

Fig. 2(a) shows the invariant mass spectrum of the $b\bar{b}$ pair in the presence of axigluons at the Tevatron for an assumed integrated luminosity of 10 fb$^{-1}$. Note that apart from the SM $b\bar{b}$ production, the background also gets a contribution from the SM dijet process due to possible mis-identification of light jets. In addition, bottom pairs are produced in $t\bar{t}$ events with almost 100% efficiency.

While, the $t\bar{t}$ background may be eliminated by demanding that there are no additional hard jets or isolated hard leptons associated with the event, there is no such straightforward scheme to do away with the dijet background and this must be taken into consideration while calculating signal significance. The invariant mass spectra for the SM $b\bar{b}$ and dijet processes are compared in Fig. 3 which shows that, once the respective tagging and mistagging probabilities are taken are taken into account, the dijet background plays only a subdominant role. Nevertheless, this contribution has been included in the distributions shown here. The NLO K-Factors are 1.17 1 and 1.3 [8, 37] for $b\bar{b}$ and dijets, respectively.

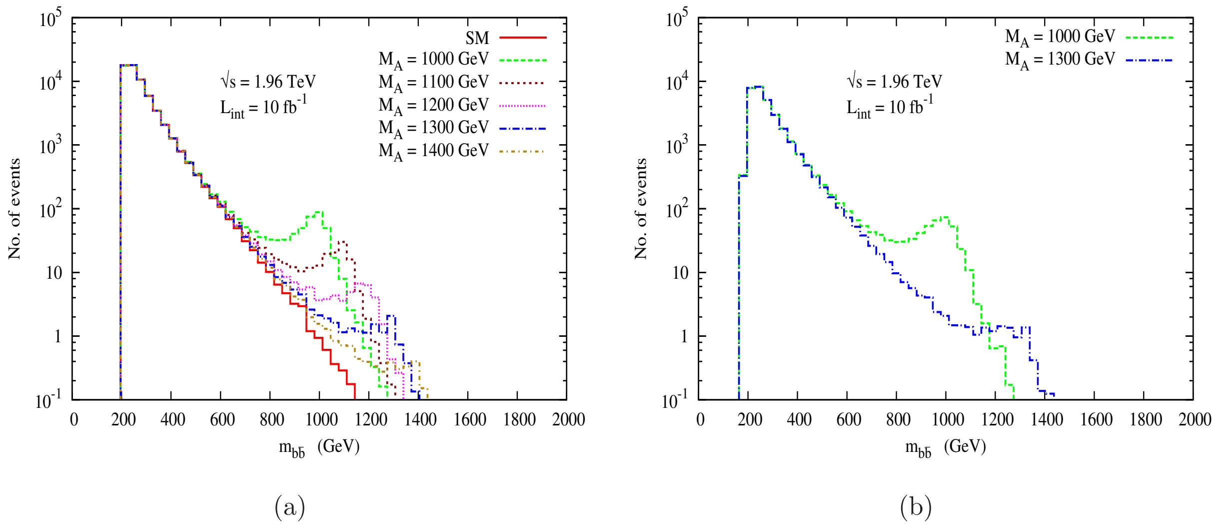



Figure 2: *$b\bar{b}$ invariant mass spectrum at the Tevatron in the presence of axigluons.* (b) *shows the effective broadening due to jet reconstruction.*

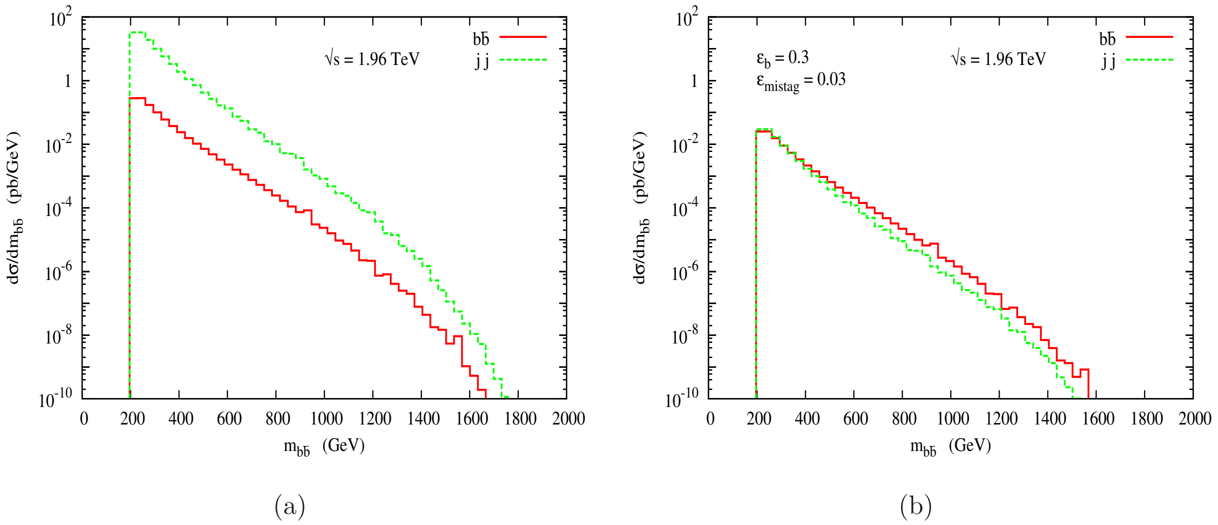



Figure 3: *Comparison between the SM backgrounds at the Tevatron due to $gg \to b\bar{b}$ and due to mistagging of dijets.*

Returning to Fig. 2(a), one sees that a resonance peak is clearly observable above the net SM background for $M_A$ upto 1300 GeV. Even for higher masses ($\sim$ 1400 GeV), a deviation in the tail of the distribution seems apparent although this region is plagued by low statistics. In the experimental scenario, it is expected that, the sharpness of any existent resonance peak would be worsened to some extent due to detector resolution effects and errors associated with the reconstruction of jets. In order to estimate the influence of such effects, the energy of the outgoing jets is smeared with a Gaussian distribution whose variance is given by the energy resolution of the central hadron calorimeter ($\sigma_{E_T}/E_T = 50\%/\sqrt{E_T(\text{GeV})}\oplus 3\%$) [8]. The effect of the smearing is shown in Fig. 2(b) for two representative cases of $\mathrm{M_A}$=1000 GeV and $\mathrm{M_A}$=1300 GeV. While a broad resonance is still distinguishable for the former, in the latter case, though the excess in the tail is conspicuous, the identification of a resonance structure appears somewhat difficult.

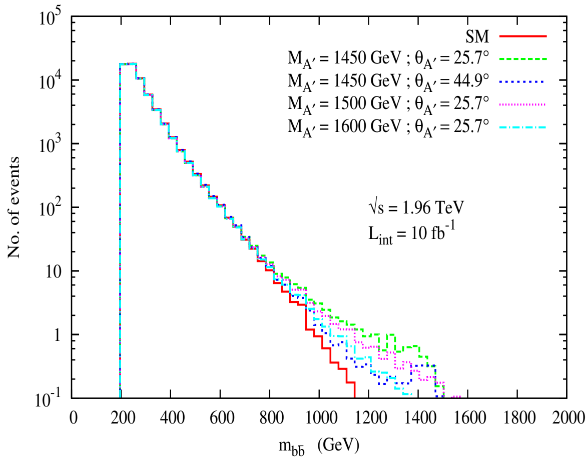


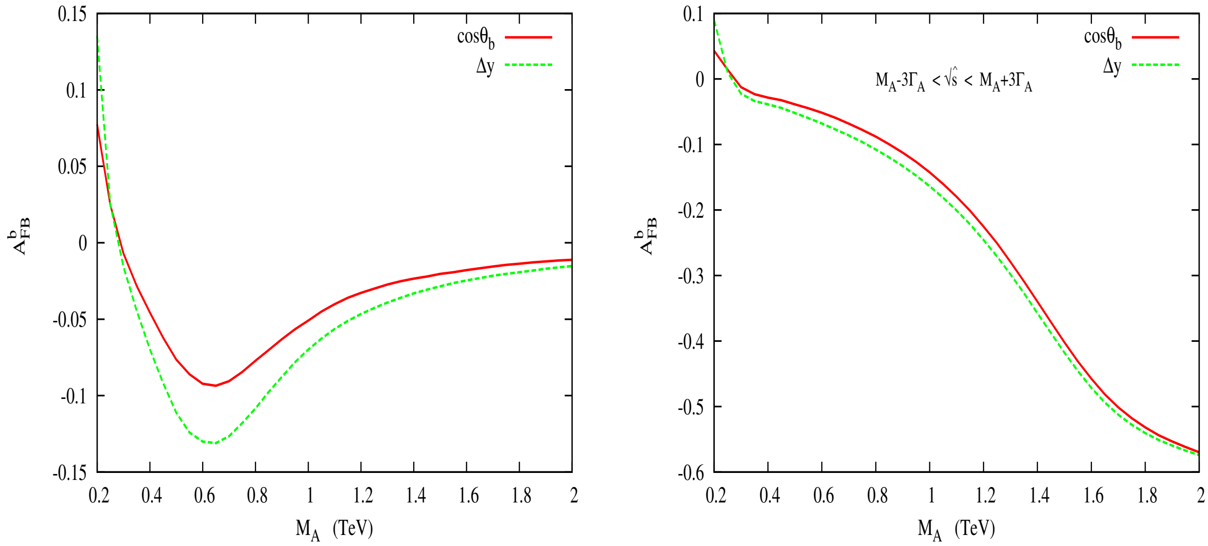

Figure 4: $b\bar{b}$ *invariant mass spectrum at the Tevatron in the presence of flavor non-universal axigluons. Parameters have been chosen so that* $\sigma_{t\bar{t}}$ *[38] and* $A^t_{FB}$ *[16] measurements are respected at the 1-*$\sigma$ *level.* $M_{A'} > 1400$ GeV *to be consistent with the* $m_{t\bar{t}}$ *spectrum [39].*

Fortunately, the presence of a resonance in the invariant mass spectrum need not be the sole indicator of the existence of axigluons. At the Tevatron, it will also be signalled by forward-backward asymmetry($A^b_{FB}$) in $b\bar{b}$ production[6]. The value of $A^b_{FB}$ can be calculated using various observables. For a given observable $\mathcal{O}$, $A^b_{FB}$ is defined as

$$A^b_{FB} = \frac{\sigma(\mathcal{O} > 0) - \sigma(\mathcal{O} < 0)}{\sigma(\mathcal{O} > 0) + \sigma(\mathcal{O} < 0)} \, .$$

The cosine of the angle made by the outgoing bottom quark with the direction of the proton beam ($\cos\theta_b$) and the difference in the rapidities of the bottom and the anti-bottom ($\Delta y$) are two observables most often used in this context. Of these, $\Delta y$ gives the value of $A^b_{FB}$ that would be measured in the centre-of-mass frame as it is invariant under boosts in the longitudinal direction. $\cos\theta_b$, on the other hand, gives $A^b_{FB}$ in the laboratory frame.

[6] At the LHC, the initial state is symmetric and no *simple* forward-backward asymmetry w.r.t the beam direction can be defined, although possible ways of constructing analogous observables that will probe the same effect have been discussed in Refs. [40–42]



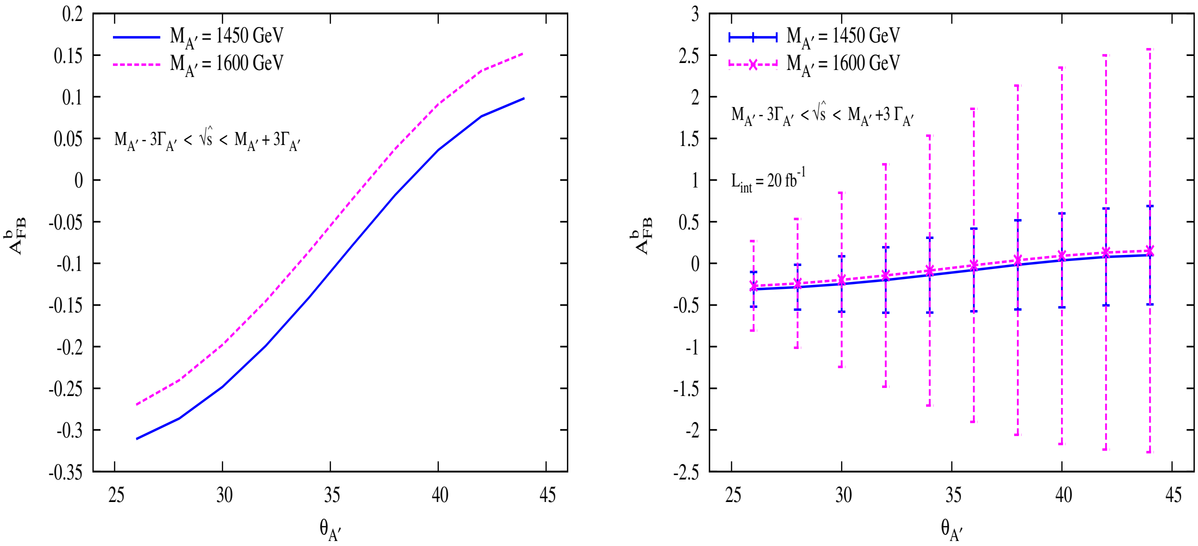

(a) (b)

Figure 5: *Variation in $A^b_{FB}$ with axigluon mass.*

The variation in $A_{FB}$ with axigluon mass is seen in Fig. 5. In Fig. 5(a) values of $A^b_{FB}$ as obtained [7] using $\cos\theta_b$ as well as $\Delta y$ are plotted as a function of axigluon mass. For most of the $M_A$ range, negative asymmetries are predicted. Note that, the asymmetry is expected to be more manifest in the region of the phase space where the dominant contribution to the cross-section comes from the axigluon mediated sub-process. This, clearly, is the region where $\sqrt{\hat{s}} \approx M_A$. If the forward-backward asymmetry is calculated in a $3\Gamma_{\rm A}$ interval around the resonance (Fig. 5(b), a monotonic behaviour is seen with the magnitude of the asymmetry growing with the mass of axigluon for $M_A > 400$ GeV.

Contribution to $A^b_{FB}$ also comes from the SM electroweak production of $b\bar{b}$ pairs. However, the magnitude of the contribution (as in the case of cross-section) is small. Further, $A^b_{FB}$ of a few percent is expected due NLO QCD effects [40,41]. Fig.3 of Ref. [40] (Fig.5 of Ref. [41]) shows the expected asymmetry in $b\bar{b}$ production from NLO QCD as a function of $\sqrt{\hat{s}}$. The asymmetry is positive and of the order of 5%-6% for $350 < \sqrt{\hat{s}} < 1800$ GeV. In comparison, consider Fig. 5(b) which shows $A^b_{FB}$, not as a function of $\sqrt{\hat{s}}$, but in a region where the value of $\sqrt{\hat{s}}$ lies close to $M_A$. Since $A^b_{FB}$ is a smooth and a slowly varying function of $M_A$ (equivalently, $\sqrt{\hat{s}}$), this correspondence is quite accurate. As can be seen, for significant parts of the parameter space, the asymmetries are, generically, large and negative. This also holds true for nu-axigluons as shown by Fig. 6(a). Thus, in both the cases, the behaviour of the new physics contribution to $A^b_{FB}$ is quite different from that of the SM contribution and tends to dominate the latter. Hence, the combined effect of SM and new physics tends to result in a significant negative value for the net asymmetry. In the event that such a negative asymmetry is observed, it would indicate contributions from such models.

[7] In the figures presented here, only tree-level new physics contributions to $A^b_{FB}$ are depicted. There is also some contribution from the SM as discussed later in the text.




(a) (b)

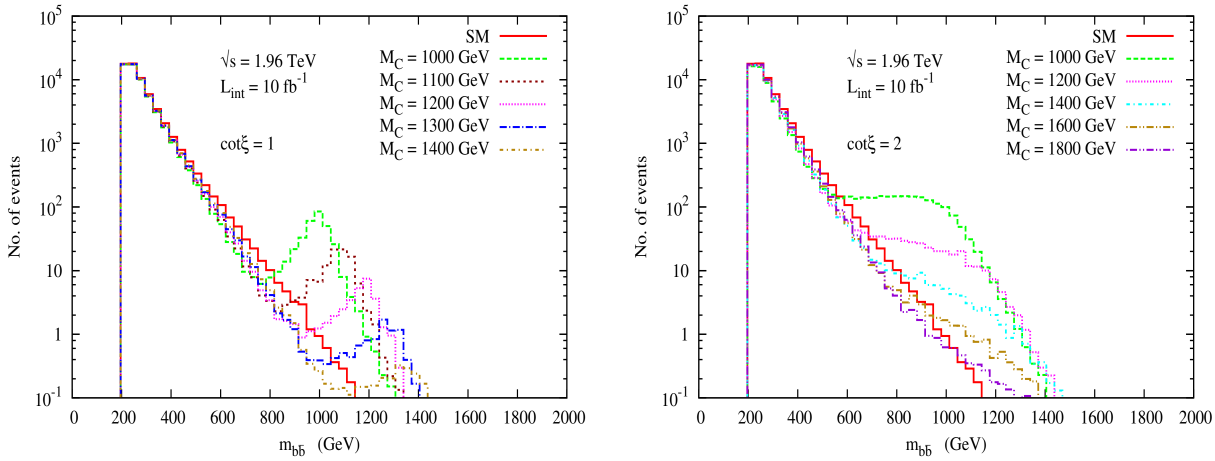
Figure 6: *Variation in $A^b_{FB}$ with coupling for nu-axigluon.*(b) *shows an estimate of the statistical errors.*

The measurement of $A^b_{FB}$, however, depends strongly on the accuracy with which the charge of the b-jet can be measured. Although such a measurement was reported at the LEP [43], the complex detector environment at a hadron collider makes this an even more challenging task at the Tevatron. A measurement of forward-backward asymmetry would be particularly interesting in the case of nu-axigluons, where, such a measurement would allow the model to be singled out as the cause for the asymmetry in the top sector [8] In Fig. 6, $A^b_{FB}$ is plotted as a function of $\theta_{A'}$. Large asymmetries are seen to be predicted. But even a naive estimate (considering only statistical errors) shows that the errors involved are large 6(b). This is simply because the $\hat{s}$ region where contribution from new physics is maximum is close to the limit of the energy reach of the Tevatron. Hence event rates are low and error bars are large.

Fig. 4 shows the invariant mass distribution for the case of the non-universal axigluon. Representative values of $M_{A'}$ and $\theta_{A'}$ are chosen from the parameter space allowed by the $\sigma_{t\bar{t}}$ [38] and $A^t_{FB}$ [16] measurements at the 1-$\sigma$ level. $M_{A'}$ is restricted to above 1400 GeV in order to respect constraints from the measured $m_{t\bar{t}}$ [39] distribution. Deviations above the background are clearly seen. Note that larger values of $\theta_{A'}$ correspond to smaller couplings.

In the case of the coloron, the deviation in the $m_{b\bar{b}}$ spectrum is apparent even in the region much below the peak. The invariant mass distributions are plotted in Fig. 7 taking $\cot\xi$=1 and $\cot\xi$=2 as two representative cases for $M_C$ values in the range 1000 GeV to 1600 GeV, along with the Standard Model background. It is seen that the spectrum dips below the Standard Model expectation before rising at the resonance. In the case $\cot\xi = 1$, while the resonance would allow the identification of colorons of mass upto about even 1300 GeV, the suppression may signal the presence of colorons of mass upto 1600 GeV. This characteristic

[8] This was also pointed out recently in Ref. [44].




(a) (b)

Figure 7: *$b\bar{b}$ invariant mass spectrum at the Tevatron in the presence of colorons with* (a)$\cot\xi$=1 *and* (b)$\cot\xi$=2

suppression of production rates in the low $m_{b\bar{b}}$ region can be used to attribute any excess present in the high $m_{b\bar{b}}$ region to a coloron, thus distinguishing it from an axigluon.

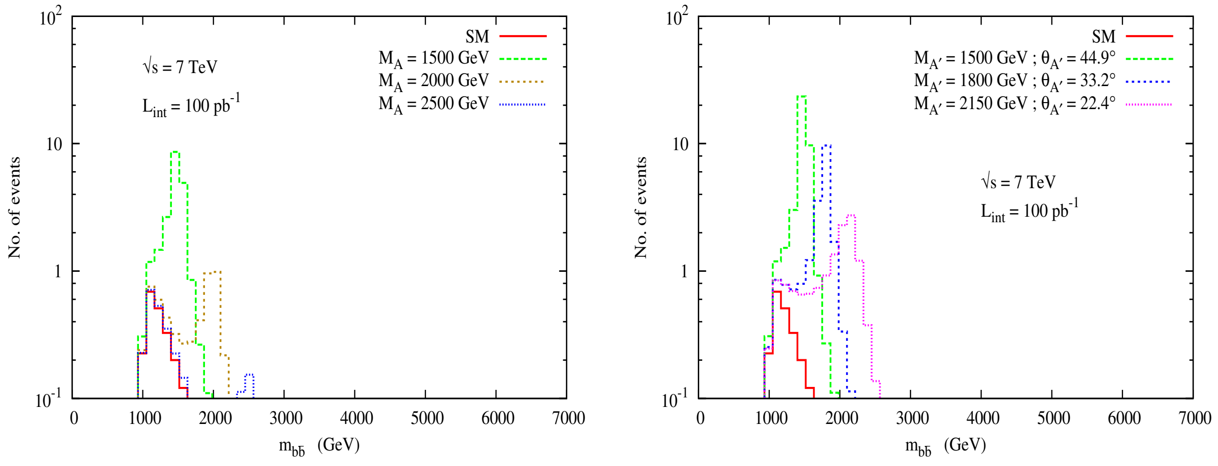
For $\cot\xi$=2, the resonance is very broad. This is likely to make the determination of coloron mass, a difficult task. Nevertheless, the spectrum is decidedly different from what is expected in the Standard Model. An excess is clearly noticeable for $M_C$ upto 1400 GeV. Here too, the suppression proves to be more useful and may be used to detect colorons with $M_C$ upto 1800 GeV. Thus, the $b\bar{b}$ channel can be used to extend the search for colorons at the Tevatron beyond currently available limits from the dijet channel.

## 4.2 At the LHC

At the LHC, the domination of the gluon initated process increases even more, creating the requirement for a more stringent $p_T$ cut. The signal suffers a further drop due to diminished the anti-quark fluxes in a $pp$ collider.

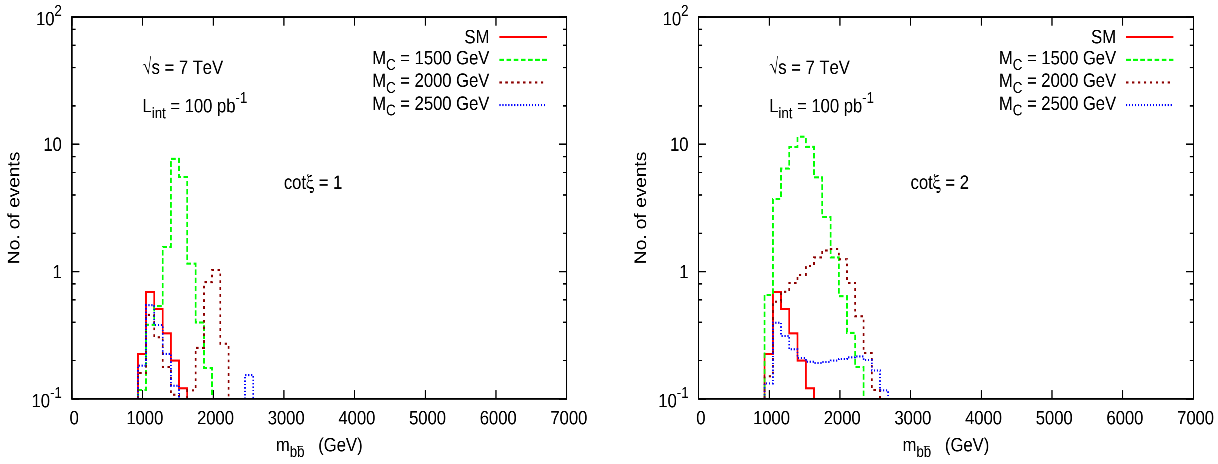
However, inspite of this, greater centre-of-mass energy allows the search to be extended into mass regions $\sim$ 2.2 TeV. The $m_{b\bar{b}}$ distributions for the different new physics scenarios are shown in Fig. 8 and 9, assuming $\sqrt{s}$ = 7 TeV and integrated luminosity 100 pb$^{-1}$. Of course, finite detector resolution will cause a broadening of the peak, nevertheless, the deviation will be sufficient so as to be considered an unambiguous signal of new physics.

Apart from the $m_{b\bar{b}}$ spectrum, the $p_T$ spectrum also gets modified in all of the above cases. The sensitivity of the $p_T$ spectrum to new physics is similar to that of the invariant mass spectrum. However, the latter fares slightly better and hence the $p_T$ distributions are not presented here. For the case of the coloron, these have been considered in detail in Ref. [45]. Of course, in the event that new physics is observed, a correlated deviation in the $m_{b\bar{b}}$ and the $p_T$ spectrum would only serve to further strengthen the claim.




(a) (b)

Figure 8: $b\bar{b}$ *invariant mass spectrum at the LHC in the presence of* (a)*axigluons and* (b)*nu-axigluons. The kinematic cuts mentioned in Table 1 have been used.*




(a) (b)

Figure 9: $b\bar{b}$ *invariant mass spectrum at the LHC in the presence of colorons. The kinematic cuts mentioned in Table 1 have been used.*

# 5 Summary

The bottom pair production process at the Tevatron as well at the LHC can be surveyed for signals of axigluons (flavor universal as well non-universal) and colorons. While all the classes of particles will appear as resonances in the $b\bar{b}$ invariant mass distribution, at the Tevatron, the measurement of a forward-backward asymmetry will be an additional indication of the existence of (nu-)axigluons. On the other hand, deficient event rates in the low and intermediate $m_{b\bar{b}}$ regions will signal the presence of colorons. While measurement of mass may be difficult for these are all broad resonances, (particularly the coloron, when $\cot\xi > 1$), the deviation would be sufficient to warrant an explanation from physics beyond the Standard Model. The $b\bar{b}$ channel can also be used to identify the non-universal axigluons as the reason behind the intriguing observation of forward-backward asymmetry in $t\bar{t}$ production.

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